Maximizing the social and ecological value of Cape Romain National Wildlife Refuge, South Carolina as the effects of global change processes increase.

Authors: Raye Nilius[1], Sarah Dawsey[1], Mitch Eaton[2], Julien Martin[3,4], Stephanie Romanach[4], Suzanne Baird[5], Mike Bryant[6], Dave Case[7], Fred Johnson[4], Jerry McMahon[2], Nancy Pau[8], Elizabeth Pienaar[9], Mary Ratnaswamy[10], Steven Seibert[11], Pamela Wingrove[6], Nate Wood[12]

Background and Decision problem

Coastal ecosystems in the eastern U.S. have been severely altered by processes associated with human development, including drainage of coastal wetlands, changes in hydrology that alter sediment and freshwater delivery to the coast, land clearing, agricultural and forestry activity, and the construction of seawalls and other structures that "harden" the coast. Sea-level rise and the changing frequency of extreme events associated with climate change are now further degrading the capacity of those ecological and social systems to remain resilient in the face of disturbance, largely through the degradation and loss of land and habitat (Fig. 1).

Coastal National Wildlife Refuges (NWRs) have an especially important role to play in sustaining valued natural resources and ecosystem services and in helping socio-ecological systems respond and adapt to the global-change processes of sea-level rise, climate change, and changing land use. The challenges faced by these refuges are immense, even before considering the added complexities and uncertainties associated with global change, and the resources available for conservation are always limited. Coastal refuge managers, in particular, have come to realize that in order for refuges to serve in this role for the future, they must also be able to respond and adapt to changing conditions that threaten to erode the values generated under (and defined by) the current mission and land base. Thus, it is imperative that scarce conservation resources be used as efficiently as possible as refuges address a mission that has become, and will continue to be, much harder to achieve. Efficient refuge management alone, however, is understood to be insufficient for fulfilling the refuge mission over the long-term. Global change processes (such as sea-level rise, climate change, and changing land use) may constrain the future ability of refuges, within their current footprints, to meet this mission. However, wise resource planning and allocation decisions in the next

[1] USFWS, SC Lowcountry Refuges Complex
[2] DOI, SE Climate Science Center
[3] Florida Fish & Wildlife Commission
[4] USGS, SE Ecological Science Center
[5] USFWS, Chesapeake Marshlands NWR Complex
[6] USFWS, NC Coastal Plain Refuges Complex
[7] DJ Case and Associates
[8] USFWS, Parker River NWR
[9] University of Florida
[10] DOI, NE Climate Science Center
[11] USFWS, NWRS Southeast Realty Division
[12] USGS, Western Geographic Science Center

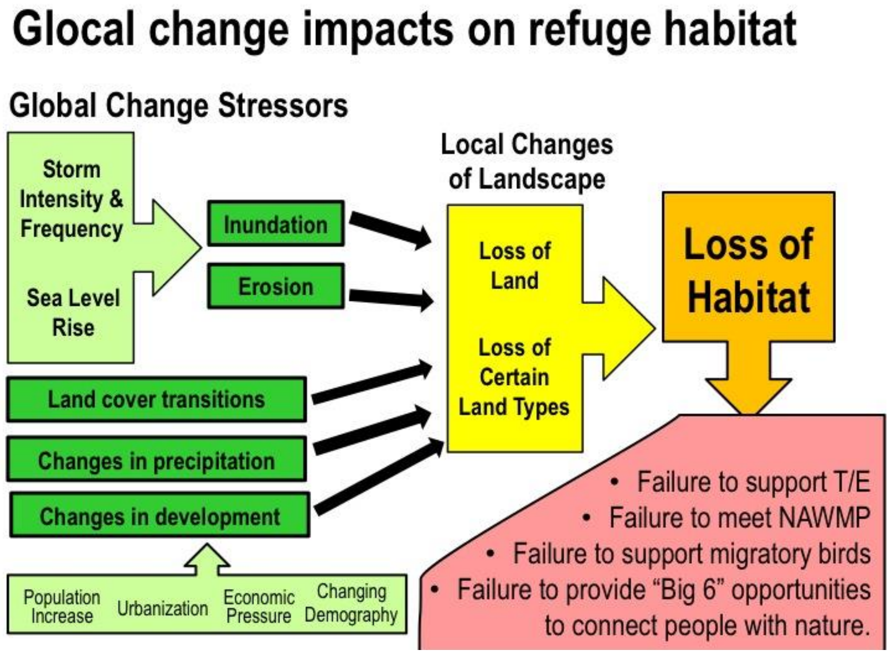

Figure 1 Global change process impacts on coastal refuge habitat. In most cases, only proximate factors are listed while ultimate causes, such as global and regional warming leading to changes in precipitation, are implied. See text for definition of "Big 6".

several years, made collaboratively with partners that have overlapping interests, may, in fact, provide coastal refuges a unique and timely opportunity to help society adapt to global change processes.

Resource allocation decisions for refuges are complicated by a mismatch between the scale of environmental variation (processes) of interest and the spatial and temporal scale at which management actions can exert an influence on refuge objectives and on the ecological processes being managed (Fig. 2, Iguchi 2011). A significant number of the challenges and, presumably, failures in conservation and management are attributable to poor understanding of, and response to, the interaction of socio-ecological processes across scales and levels (Cumming et al. 2006, Guerrero et al. 2013). The refuge has limited control, authority and resources to fully realize conservation objectives for wide-ranging, migratory species that may only spend a portion of their complete lifecycles in refuge habitats. Although the governance structure of the regional NWRS may result in an appropriate matching of scales for some decisions (e.g., resource allocation at region or flyway perspective), many decisions are made at the refuge level where the likelihood of scale-mismatch are increased. Individual refuges face a considerable challenge in defining achievable yet meaningful objectives while, at the same time, expanding the scale of the decision context by considering a broader set of stakeholders and expressing the significance of the refuge in terms that engender broader societal support.

To help address these challenges, we worked with coastal refuge managers to articulate a two-track decision problem. In this prototype decision structure, we have attempted to describe a hierarchical set of objectives, performance metrics and

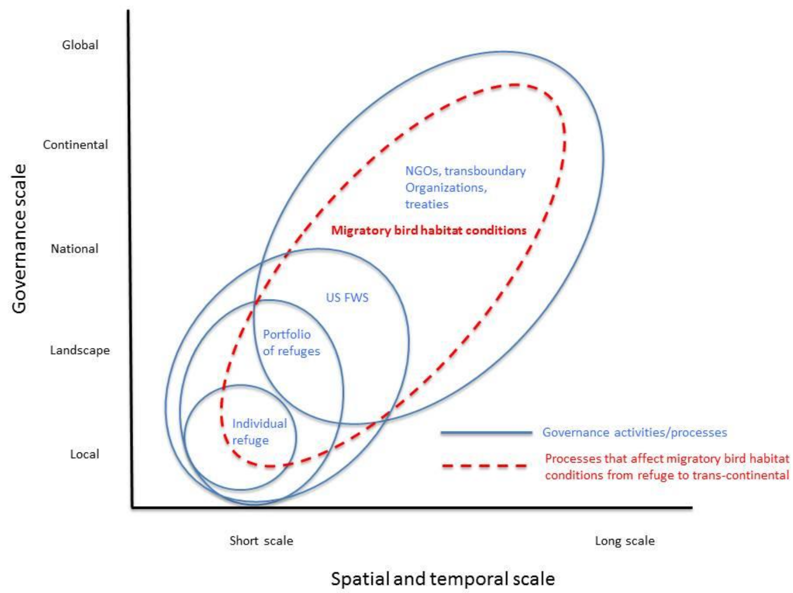

Figure 2. A representation of interactions across spatial, temporal, ecological and organizational scales. Depicts the complexity of matching the decision context (i.e., governance structure) to ecological or other processes that operate across levels within a given scale. After Cash et al. 2006.

actions in recognition of issues stemming from multiple ecological and sociological scales. We also try to characterize a balance between decisions within the purview of the individual refuge and the critical decision context (i.e., refuge expansion) needed to ensure the persistence of the refuge but not within full control of its staff. Although some of the particular elements vary across individual refuges, the challenges addressed are common to many coastal refuges. Cape Romain National Wildlife Refuge (CRNWR) served as the focal site for developing the specific considerations of this decision prototype, with the desire for a generally applicable framing of decision problems faced by refuge managers, and for an understanding of the extent to which those decisions might be influenced by other agents who have either common or competing interests. The goal was to develop a problem framing that would broadly reflect the type, scale and scope of SLR-adaptation decisions faced by refuges in general, and that could be used by individual refuges to help understand how their specific problems fit into a larger context of SLR planning and implementation. We worked with refuge managers in developing a common frame of reference for some shared SLR-related management problems, while also facilitating communication about these problems with other refuges and with surrounding jurisdictions.

The first track focuses on efficient allocation of finite staff-time and budgets for management of existing programs and resources under the current refuge design. Acknowledged as a near-term solution, refuge managers must make informed resource allocation decisions to minimize, or protect against, loss in the capacity to meet the refuge mission within their current refuge footprint. Impacts of global change processes are contributing to this decline. Assessment of the impacts of alternative management actions on achieving these goals, and subsequent allocation decisions, are implemented largely at the refuge level subject to an annual operational budget constraint.

The second track implicitly recognizes that global change processes negatively affect the social and ecological values derived from the existing refuge configuration. Over the longer term, refuge managers must decide when and where to acquire or protect new land/habitat to supplement or replace the existing refuge footprint in order to sustain refuge objectives (and, possibly, the public good) as the system evolves over time. Creating and implementing a strategy for expanding refuge capacity to sustain the refuge mission is likely to involve capital allocation decisions out of the direct control of the staff of an individual refuge, including FWS regional and national staff. It is unrealistic to expect that a major refuge expansion could occur solely using federal funds (such as the Land and Water Conservation Fund). Therefore, efforts to expand refuges to meet these changing needs will require the creation of partnerships and the identification of a set of common objectives and funding sources that the partners, including the refuge, are willing to bring to bear in a collaborative manner.

The theme common to both of these problems (Track 1: resource allocation; Track 2: reserve design) is developing an approach to minimize the cumulative loss of value (as defined by refuge objectives) over time as conditions change in the refuge and surrounding landscape, conditioned on budgetary and staffing constraints. Each track proposes a unique set of alternatives to represent differences in the identity of the decision maker(s) and in spatial, temporal and governance scales of the decision

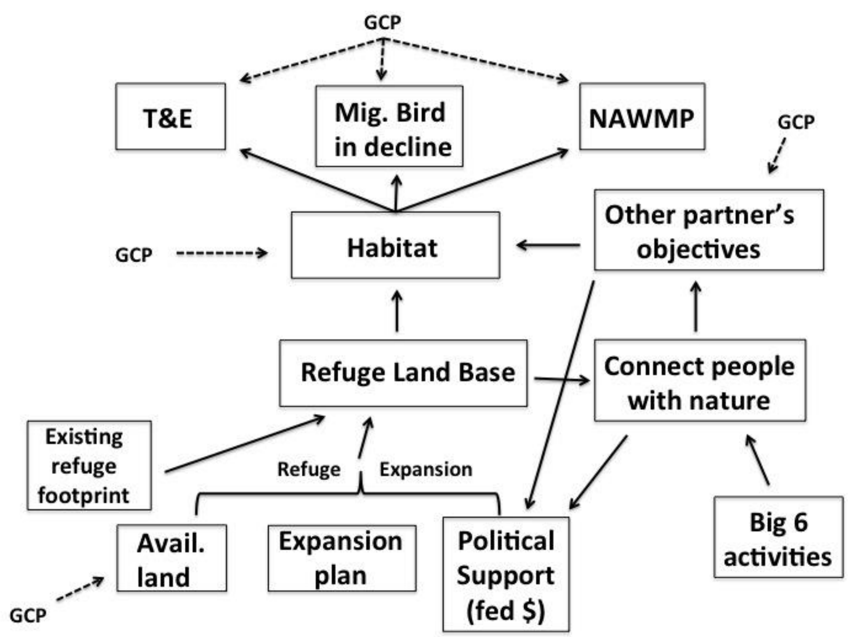

Figure 3 Conceptual models of systems and processes that affect coastal refuges. Terms: Global Change Processes (GCP), North American Waterfowl Management Plan (NAWMP), Threatened and Endangered Species (T&E), public engagement (Big 6 activities). Acronyms defined: GCP (global change processes), NAWMP (North American Waterfowl Management Plan), Big 6 (visitor experience activities; see text under 'Means Objectives'), T&E (threatened/endangered species)

problem. Minimizing loss associated with coastal refuge objectives is tied to decisions made within the context of a refuge system that is created and constrained by a combination of social, physical, chemical, and biological processes operating at a variety of scales (Fig. 3). We developed a prototype decision structure by describing how a hierarchical set of objectives and alternative actions can be used to explore the tradeoffs inherent in making short- and long-term adaptation decisions. In the uncertain world of climate change, good decisions don't guarantee good outcomes, but a systematic process, in which decision makers (managers) and scientists are fully engaged in all aspects of the problem, should enhance the likelihood of good outcomes.

To explore these tracks, we followed general guidelines for the framing of decision problems provided by Keeney (1992). We used a decision-analytic approach, meaning that decision problems are explicitly structured in terms of choices, outcomes, and values in order to identify the choice that is most likely to meet stated objectives. Decisions involve both predicting outcomes from alternative choices and valuing those outcomes. The first part is the (objective) role of science and the second part is the (subjective) role of the decision maker (and, ultimately, society). Discussions were "values focused" (Keeney 1992) in the sense that the ecological, social, and economic values the refuge supports were recognized as the key to developing and evaluating adaptation choices. Objectives (values) are discussed first, and drive the rest of the decision analysis. Emphasis was placed on the recognition that objectives should be sufficient to fully evaluate all the alternatives and alternatives should be sufficient to describe all the various ways in which the objectives could be achieved; i.e., the objectives and the set of alternatives appropriate to consider for the particular situation are interdependent and should match in scale in order to increase the likelihood of successfully framing and solving a decision problem (Keeney 1992).

Refuge Objectives

Refuge managers and staff recognize that refuge objectives, like the current refuge boundaries, are not immutable. However, current regional workforce planning criteria provided us with a starting point to identify four primary objectives that have been distilled to represent the overall Mission of the National Wildlife Refuge System: "to administer a national network of lands and waters for the conservation, management, and where appropriate, restoration of the fish, wildlife, and plant resources and their habitats within the United States for the benefit of present and future generations of Americans." We have paraphrased this Mission statement to "maintain biological integrity" for ease of discussion and graphical representation.

These objectives, considered to be fundamental to the larger NWR System Mission, and society in general, are to (1) maximize protection and recovery of threatened and endangered species; (2) maximize habitat for and protect populations of migratory birds and at-risk species in decline; (3) meet waterfowl goals of the North

American Waterfowl Management Plan (NAWMP); and (4) maximize opportunities for the public to connect with nature.

A fifth objective, which can be thought of as a strategic objective that is required to meet the first four objectives, is to maximize the longevity or sustainability of CRNWR. Because the refuge can only affect the first four objectives conditional on meeting this fifth objective, we classify it as a constraint that must be met (i.e., its performance cannot be traded-off for improvement on another objective). However, significant time and resources may be required to meet this objective; therefore, some means to assess an efficient allocation of energy to this objective is warranted. We did not address this need during the initial prototyping exercise.

Figure 4 presents an objectives hierarchy demonstrating the relationship between fundamental values and means to achieve these objectives. In essence, there are 2-3 hierarchical levels of fundamental objectives representing different possible scales at which to match the context of the decision problem. The highest order fundamental objective (F1) – maintaining biological integrity – is broader than the decision context that the refuge can affect. The lowest-order fundamental objectives (F3) – particular species and resources - is currently the level at which the refuge is managing. These are appropriate and measurable objectives but should be considered carefully – future conditions may affect species distributions such that any action taken by the refuge will have little impact and achieving success at this level will be unachievable. Therefore, more inclusive categories (F2) for species that are currently, or will be, dependent on the refuge for population persistence was determined to be at the correct scale-match for CRNWR decisions in the present and future.

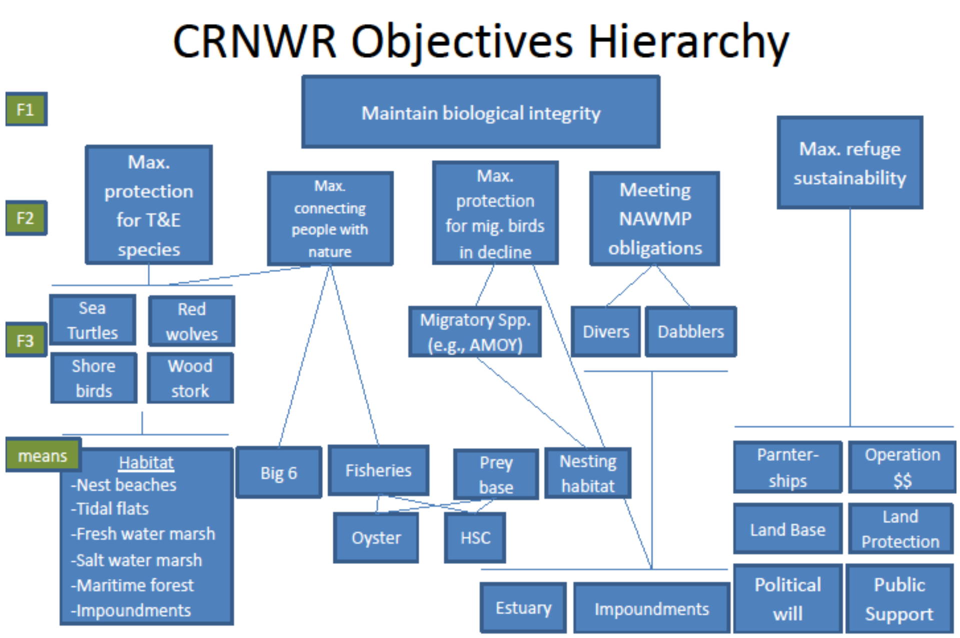

Figure 4. Objectives hierarchy developed for Cape Romain NWR. Levels F1-F3 represent a hierarchy of fundamental objectives that provide a range of scales for appropriately matching a given decision context. HSC= habitat suitability criteria; AMOY=American oystercatcher.

The scale of the objective "Refuge Sustainability" lies somewhere between F1 and F2 given that decisions regarding regional funding allocations and the possibility of relegation of refuges into 'custodial status' (i.e., little to no active management, staffing reductions, restricted visitor access) are not those of CRNWR. The refuge does have the ability, however, to allocate resources to activities that will engender greater public and political support for allowing CRNWR to continue its mission. Recognizing the relative difference in scale of this objective provides the opportunity to expand our thinking to consider the value of the refuge in the context of a broader set of societal benefits. Because we will necessarily include a larger set of stakeholders in this context, we may need to predict and evaluate decisions with respect to this objective using different attribute measures to reflect the increased scale (see below, Performance Metrics).

Means Objectives

Sustaining the first three fundamental refuge objectives begins with the availability of adequate habitat (amount, quality) at the right time and place to meet the needs of species that use the refuge (figs 3 & 4). Wildlife dependent recreation also forms the basis for connecting people with nature (Obj. 4) – each of the major classes of public engagement (the 'Big 6': hunting, fishing, wildlife observation, wildlife photography, environmental education, interpretation) is dependent on adequate habitat and a sufficient and diverse land-base. The particular components (e.g., species, activities, etc.) of each fundamental objective require specific habitat types (Fig. 4), the appropriate composition of which will be governed by the relative weighting of objectives by the refuge. Because habitat is considered as a means to achieve our fundamental objectives, we do not limit evaluation of habitat availability as exclusively provided by the refuge land base but also by partnerships and nearby lands not directly under refuge control but contributing to refuge objectives nonetheless. The value of non-refuge lands to refuge objectives may happen by chance – i.e., landowners meeting their own, complementary objectives – or through creation of deliberate partnerships with the refuge.

Alternatively, the means to achieve refuge sustainability revolve around the ability to demonstrate and communicate the value of CRNWR and its mission to the broader public and those decision makers who could affect the longevity and effectiveness of the refuge. Public support and political will for CRNWR may directly influence the likelihood of maintaining sufficient annual operating budgets for land protection and of expanding the refuge land-base in response to global change stressors and loss of coastal habitat resources.

Performance Metrics

Metrics proposed for use in predicting the outcome of decisions and evaluating the degree of successfully achieving stated objectives differed between the two prototyped decision tracks. Under the first track (refuge allocation), performance metrics are oriented towards the response of species currently managed on the refuge (Table 1). For track 2 (reserve design), metrics proposed during the second prototype were broadened to include index measures of diversity and abundance for Objectives 1 & 2 (threatened & endangered species, declining migratory species) to accommodate the possibility of changing community composition over time (Table 2). For the prototype exercise, this metric was simplified to an index. Additionally, the acreage of habitat types (generalized to upland vs. wetland) was adopted as a proxy measure for habitat-dependent species guilds that may use the refuge in the future. It is anticipated that habitat categorizations will be expanded to reflect further specific species-habitat relationships identified as needed to sustain a diversity of migratory species. We also intend to develop additional metrics to reflect other habitat characteristics important for species protection (e.g., threshold habitat quantities, spatial configuration, successional dynamics, etc.).

Decision Alternatives

Alternative management actions that are considered for evaluation under the two tracks differ substantially. Under the allocation track, we identified classes of management actions that included restoration activities (e.g., control of invasive species, habitat restoration), water management (e.g., impoundments for particular species-groups), protection (e.g., enforcement, signage, communication with partners), visitor services (e.g., tourism, volunteer management, education programs) and direct species management (e.g., turtle nesting program, red wolves). We selected a subset of possible activities under each category to demonstrate the concept of constructing a portfolio of individual activities to maximize refuge objectives, constrained by the annual operating budget or limits on available personnel time (Table 3). Evaluation of the optimal return on management effort within the refuge boundaries will then be carried over to the reserve design problem (Track 2) to compare trade-offs of committing management resources to protecting the current refuge versus devoting effort to expanding or migrating the refuge land-base.

Table 1. Performance metrics selected for within-refuge allocation problem (Track 1).

Objective	Performance Metrics	
Increasing T/E species	Turtles	Number of nesting females Number of hatchlings returned to sea % of nesting success
	Shore birds	Linear miles of protected shorelines Area of protected islands Number of birds Location of birds
Supporting declining migratory birds	Number of birds (abundance) Number of bird species (diversity) Nesting habitat availability	
Improving NAWMP	Number of ducks Acres of appropriate habitat	Depth and salinity of impoundments % of open water in impoundments
Connecting People to Nature	Total number of visitors/year Number of visitations (activity based)	
*Refuge Sustainability	Available acres Available funding	

Table 2. Performance metrics selected for the reserve design problem (Track 2)

Objective	Performance Metrics
Increasing T/E species	Diversity and abundance (constructed index: 1-10)
Supporting declining migratory birds	Diversity Index (1-10) Upland Habitat (acres) Wetland Habitat (acres)
Improving NAWMP	Duck Abundance (Constructed index: 1-10)
Connecting People to Nature	Total number of visitors/year
*Refuge Sustainability	Available acres Available funding

Table 3. Example of decision alternative categories and specific actions under consideration for allocation problem

CATEGORY	ACTION
Restoration	invasive species control
	oyster reef restoration
	beach nourishment
water management	impoundment, waterfowl
	impoundment, shorebirds
	impoundment, wading birds
resource protection	water quality monitoring
	Posting
	LO patrol
	LO enforcement
	develop partnerships
	congressional coordination
direct species management	turtle, protection 1
	turtle, protection 2
	turtle, protection 3
	monitoring and inventory, level 1
	monitoring and inventory, level 2
	red wolves
land acquisition	minor expansion
	major expansion
visitor service	environmental education
	time spent with concessionaire
	management of volunteers, low
	management of volunteers, high
	coord with Friends of CR, low
	coord with Friends of CR, high

The focus of a reserve design analysis is to identify those land parcels in the landscape surrounding CRNWR that will maximize refuge value as specified by the fundamental objectives. Hypothetical alternatives for this track were of two types: land parcels currently identified under a minor expansion process, and a much larger set of possible parcels existing outside of the current expansion plan (representing a major expansion plan). A major refuge expansion is a formal process that depends on three conditions occurring at the same time: available land (i.e., willing sellers at a price that the refuge is allowed to pay); an expansion plan that encompasses this tract of land; and political support, expressed in federal funds. To develop our second prototype, we identified 27 land parcels in the region of the Santee River from which we could select in designing a future refuge (Fig. 5). In subsequent prototyping, we will expand the list to include potential parcels across a wider landscape, the extent of which is still to be defined. Land acquisition decisions will necessarily include associated considerations of allocating staff time and efforts. For example, political support is provided directly and indirectly by individuals and organizations willing to advocate for refuge expansion. It is assumed that this support is enhanced by the quality of refuge programs that connect refuge visitors to nature, increasing the recognition by the public of enhanced benefits associated with refuge lands (e.g., storm protection, elevated property values, etc.) and also by refuge collaborations with individuals and organizations that are mutually advantageous and create both good will and a desire for the ongoing existence of the refuge.

Dynamics and predicting consequences

For the purposes of prototyping the decision analysis, we relied on expert opinion to link the management alternatives under either decision track to expected outcomes, as measured in units identified under each objective's performance metric. To ground this expert opinion, we had available modeled predictions of SLR at Cape Romain for 3 periods (2020, 2050 and 2080), based on local ocean height, thermal expansion, ice melt, land water storage and vertical land movement (excluding sediment accretion and groundwater withdrawal)(Horton 2014, unpublished data; Table 4). We applied these estimates using the NOAA Sea Level Rise and Coastal Flooding Impacts Viewer (http://www.csc.noaa.gov/digitalcoast/tools/slrviewer) to visualize marsh migration and other SLR impacts under different climate

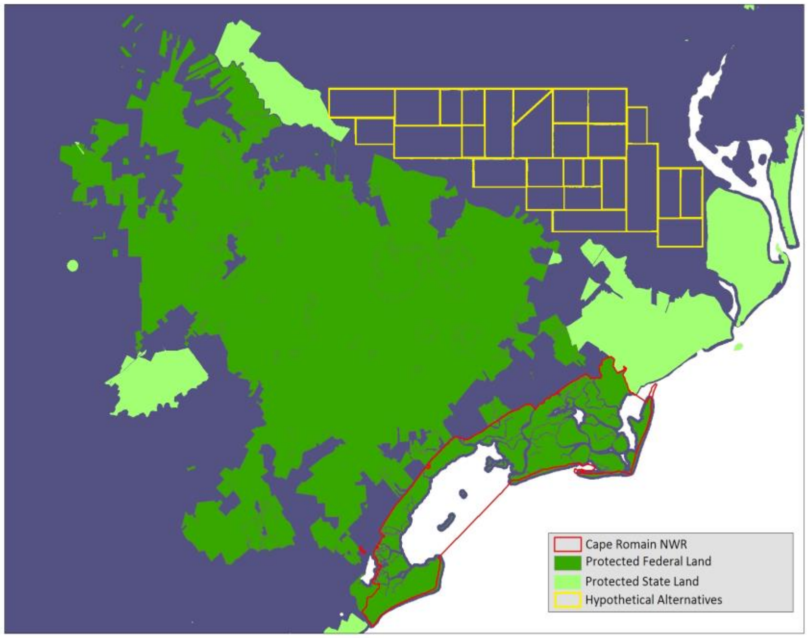

Figure 5. CRNWR, other protected land and hypothetical acquisition alternatives along the Santee River under a reserve expansion plan.

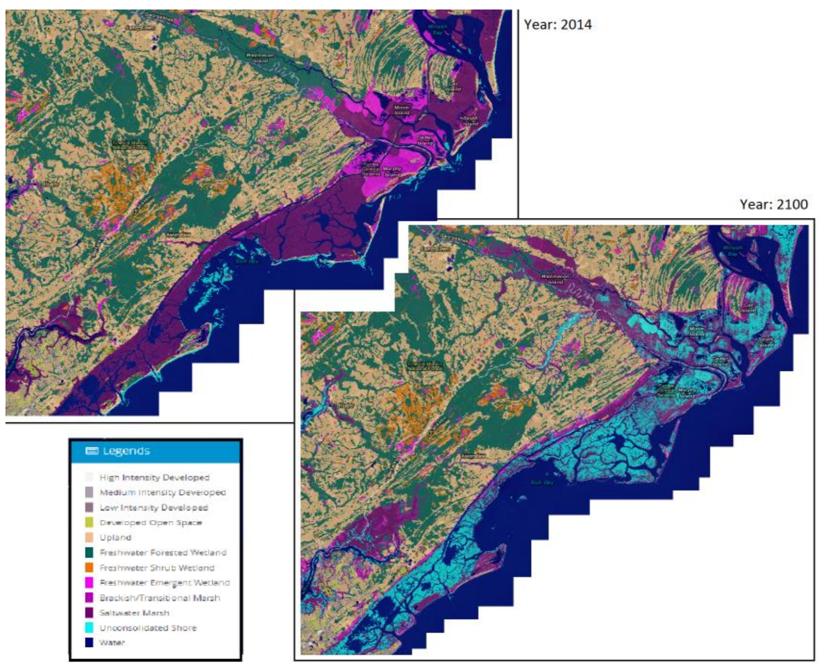

Figure 6. Predicted marsh migration and other vegetation response by 2010 under a 2-ft SLR scenario.

scenarios and timeframes (Fig. 6). In subsequent prototypes, we will attempt to develop more formal predictions of the functional responses of species (or guilds) to habitat types, habitat dynamics and disturbance. This effort will begin with identifying and working with subject matter experts in a number of fields (e.g., geomorphology, wetland & forest ecology, avian and T&E species biology, sociology, etc.) to first develop conceptual models to describe hypothesized relationships between global change stressors, habitat dynamics, management interventions and species abundance or demographic performance. From these, numerical estimates of changes in response variables (i.e., performance metrics) over time will be estimated. Parameter values for these predictive models will be obtained from existing data sets, from the scientific literature, or elicited from experts if data are not available.

For the purposes of the rapid prototype exercise, we simply demonstrated the use of a multi-objective consequences table as a way to link management decisions (alternatives) to fundamental objectives and prepare the problem for a trade-off analysis. For the allocation track, we simplified the problem by evaluating short-term management outcomes (i.e., ignoring the future and temporal dynamics), focusing on the consequences to objectives of implementing proposed management alternatives within the current refuge boundaries. For the reserve design track, we added an incremental degree of complexity by predicting both the current and future (2040) consequences of including individual land parcels (n = 14) in the refuge design (Table 5). The two scores were simply combined to produce a final valuation of each land parcel, with additional realism (i.e., discounting of future values) to be added in the next prototype. Although the evaluation of management outcomes was spatially explicit (parcel locations were explicit and mapped to predictions of SLR/marsh migration), the benefits resulting from each parcel were independent and additive as noted above (i.e., there was no consideration of reserve configuration, parcel connectivity or threshold effects of reserve size and human visitation). We are now developing more comprehensive methods for incorporating temporal component of resource dynamics under global change processes. These will be in the form of state-transition models which describe non-deterministic transition probabilities among discrete habitat categories as a function of disturbance, management or other covariates. We will also consider broader impacts and benefits of reserve design alternatives (e.g., on local/regional economies, storm protection and other ecosystem services to surrounding communities, etc.), the effects of urbanization on parcel availability, connectivity and price, and major sources of uncertainty in transition parameter estimates or other predictions.

Table 4. Predicted SLR and uncertainty estimates for the South Carolina coast (Horton 2014, unpublished)

	Low-estimate (10th percentile)	Middle Range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	2 in	3 to 6 in	8 in
2050s	6 in	9 to 17 in	25 in
2080s	10 in	15 to 33 in	49 in

Trade-off Analysis and Optimization

For the majority of multi-objective decision problems, achieving benefits for one objective comes at a price for other objectives, requiring a careful consideration of trade-offs to maximize the overall management benefit. One impediment to making systematic and unbiased trade-offs is the reality that objectives are quantified on different scales and using different units of measure. To address both issues, we used a value function approach to express the relative value to the decision maker of particular outcomes for a given objective. A value function assigns a number to each consequence (i.e., each level of a performance metric) to reflect the relative desirability of an outcome (Keeney 1992). This approach allows attitudes towards risk to be incorporated as a component of the expression of values and normalizes units of measures to a zero-one scale to permit comparisons among objectives. For example, if the goal of refuge managers is to support a minimum of 1200 nesting sea turtles each season, a convex value function reflects this desire by expressing a low return on any management decision that results in fewer than 1200 nests, contrasted by a rapid gain in benefits for decisions producing successful nests at or above this 'utility threshold' (Martin et al. 2009; Fig. 7). Although we began with linear value models (i.e., the gain in utility for each unit increase in the outcome is equal across all outcomes), these functions can take any form and will be developed further as we identify specific refuge values. The goal of these models is to add clarity to complex trade-offs and offer insights into the influence of values on the decision process.

While the value models represent a form of weighting outcomes within the context of each objective independently, we also allow for decision makers to express their values across the full set of management objectives as a set of relative weights for each objective such that they sum to 1. The consequences of each decision alternative for each objective, first translated to a normalized utility value via the value model, is then multiplied by the objective weight to produce a weighted and normalized score for that alternative. These scores are summed across all objectives for each alternative, computing a total weighted score for the alternative. The total score for each alternative serves as the basis for comparing among decisions for subsequent trade-off analyses.

Because, in both decision tracks, we are not attempting to select the best single alternative to implement but instead want to allocate limited budget and personnel resources to the optimal portfolio of activities, we prototyped a constrained optimization approach using linear programming. This method optimizes the selection of a set of available alternatives based on their performance score and constrained by the total budget. By optimizing the portfolio across a range of current and future budget scenarios, we develop an 'efficiency frontier' of Pareto optimal solutions (Polasky et al. 2008, Bode et al. 2011), in which any portfolio of activities for a given budget that lies below this line is sub-optimal (Fig. 8). This line then describes the rate of management benefits returned (or lost) as budgets

Table 5. Multi-attribute consequence table applying a rapid elicitation of predicted values to hypothetical land parcels under consideration for expanding the boundaries of CRNWR. The combined weighted value for each objective is the product of a normalized utility value for each outcome and the objective weight, summed over the present and future value. The utility values, in this case, were linear functions over the range of predicted outcomes, but could take other forms to represent more specific desires of managers for a resource (see Fig. 6).

	Waterfowl		T&E (Div/Ab)		People		Mig. Birds (Div/Ab)		Mig. Birds (Habitat)				Cost	Combined weighted value						
	Index, 1-10		Index: 1-10		Total visits		Index: 1-10		upland (ac)		wetland (ac)		($M)	Waterfowl	T&E	People	Mig. Birds			Total
Wt	0.05	0.02	0.08	0.11	0.06	0.06	0.11	0.17	0.06	0.08	0.08	0.11								
parcel	today	2040	today	2040	today	2040	today	2040	today	2040	today	2040		Index	Index	Visits	Div/Ab	Upland	Wetland	
1	3	5	5	8	5000	10000	5	7	3750	4500	3750	4500	27	0.032	0.105	0.126	0.111	0.147	0.188	0.709
2	3	5	5	8	100	200	5	7	152	114	228	266	1.1	0.032	0.105	0.003	0.111	0.005	0.009	0.263
3	3	5	5	8	500	800	5	7	640	480	960	1120	5.3	0.032	0.105	0.011	0.111	0.020	0.046	0.324
4	3	5	5	8	50	100	5	7	377	283	565	659	3.2	0.032	0.105	0.001	0.111	0.012	0.026	0.286
5	3	5	5	8	0	0	5	7	360	240	840	960	3.2	0.032	0.105	0.000	0.111	0.010	0.039	0.297
6	3	5	5	8	0	0	5	7	130	65	520	585	1.8	0.032	0.105	0.000	0.111	0.003	0.023	0.274
7	1	1	5	8	500	1000	5	8	694	657	37	73	3.5	0.000	0.105	0.013	0.195	0.024	0.000	0.337
8	3	5	5	8	100	200	5	7	72	58	72	86	0.54	0.032	0.105	0.003	0.111	0.002	0.001	0.253
15	3	3	6	6	5000	10000	7	7	2800	2450	700	1050	15.2	0.025	0.077	0.126	0.163	0.093	0.038	0.522
16	5	7	6	8	5000	10000	4	6	1200	1000	800	1000	7.6	0.056	0.147	0.126	0.000	0.039	0.039	0.408
17	7	7	7	8	5000	10000	8	8	200	0	3800	4000	6.2	0.074	0.189	0.126	0.274	0.003	0.178	0.844
18	7	7	7	8	5000	10000	8	8	48	0	903	950	1.4	0.074	0.189	0.126	0.274	0.001	0.040	0.704
23	3	5	5	5	200	500	5	6	230	201	57	86	1.1	0.032	0.000	0.006	0.026	0.008	0.001	0.072
24	7	7	7	8	50	100	8	8	6	0	117	123	0.194	0.074	0.189	0.001	0.274	0.000	0.003	0.541

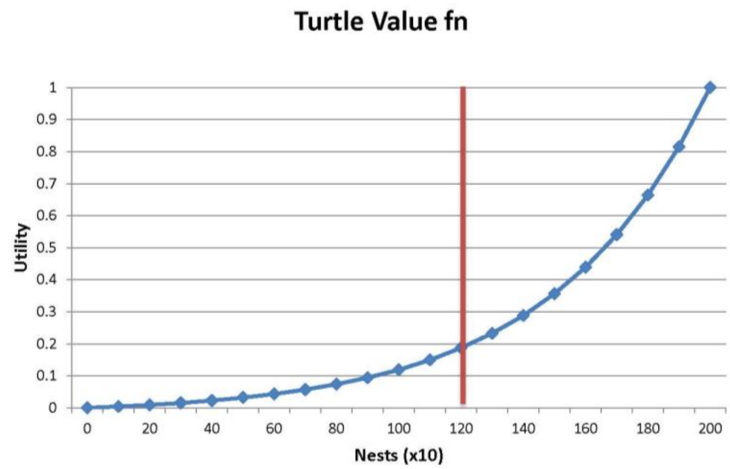

Figure 7. A hypothetical value function that demonstrates greater utility (i.e., satisfaction) only once management actions result in a minimum of 1200 nesting females. Value statements such as these influence decisions by driving trade-offs to achieve the greatest utility.

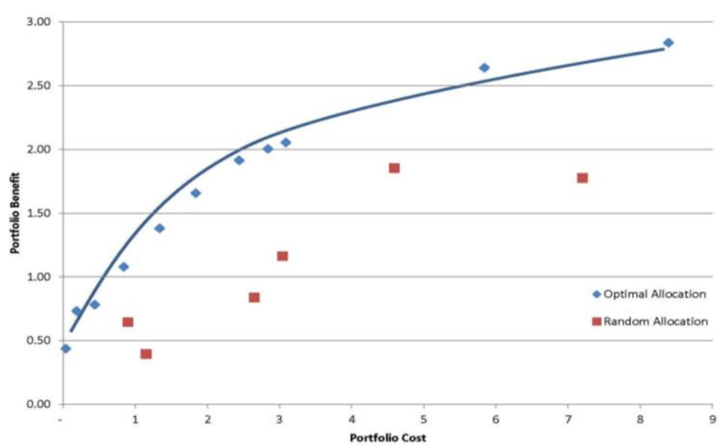

Figure 8. A Pareto efficiency frontier indicating optimal portfolio performance for any given budget constraint (in blue). Dominated alternatives (red) are those in which higher performance can be achieved for the same budget or equal management benefits can be achieved at a lower cost.

increase (or decrease). Budget 'zones' demonstrating a high marginal return rate provide a strong justification for additional funding (if current budgets are below this amount) or a rationale of explicit efficiency for maintaining current funding (if in the target 'zone'). We solved the linear programming problem using the add-on package SOLVER in Microsoft Excel[1]. For these prototypes, we limited constraints to annual budget scenarios, recognizing that modeling other constraints and conditions is possible. For example, a reserve-design process might consider meeting a desired diversity of habitat types (e.g., the proportion of wetland to upland habitat), a minimum connectivity or edge-to-area metric, or the proportion of fee-simple acquisitions versus partnership lands. The output from the optimization would be the selection of parcels recommended for purchase or protection that maximizes the cumulative objective score for present and future value, conditional on the stated constraints (see Fig. 9, depicting a one-time decision across 3 budget constraint scenarios). For the refuge allocation problem, other portfolio constraints might include an equitable distribution of activities among the major classes of alternatives, a maximum number of activities in any particular category or a cap on budget or personnel time expended on any single alternative.

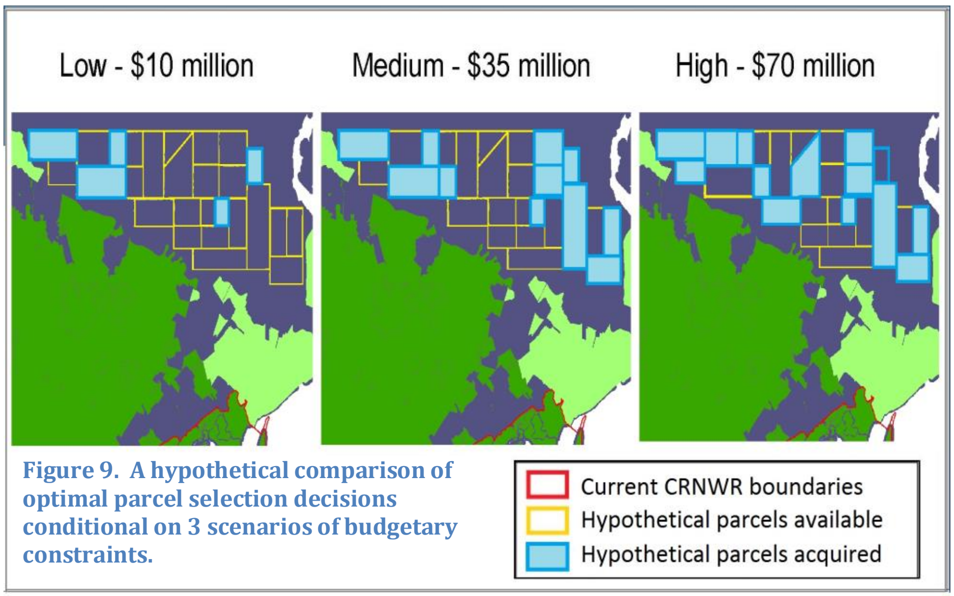

Figure 9. A hypothetical comparison of optimal parcel selection decisions conditional on 3 scenarios of budgetary constraints.

Two additional outputs from the trade-off analysis include an evaluation of the decision robustness across uncertainty and a breakdown of management benefits by objective. We demonstrate the robustness of parcel selection across a range of budget scenarios ($5 – 80M) in Fig. 10a, where the proportion of scenarios in which each parcel was selected is represented by bar height. Those parcels included in an optimal portfolio under all budget situations have characteristics that make them robust to political uncertainties, whereas parcels with lower inclusion rates are

[1] Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

optimal only under specific conditions. Quantifying the relative benefits by management objective (Fig. 10b) is useful when conducting sensitivity analyses on the effect of values (objective weights) or assumptions about model predictions for

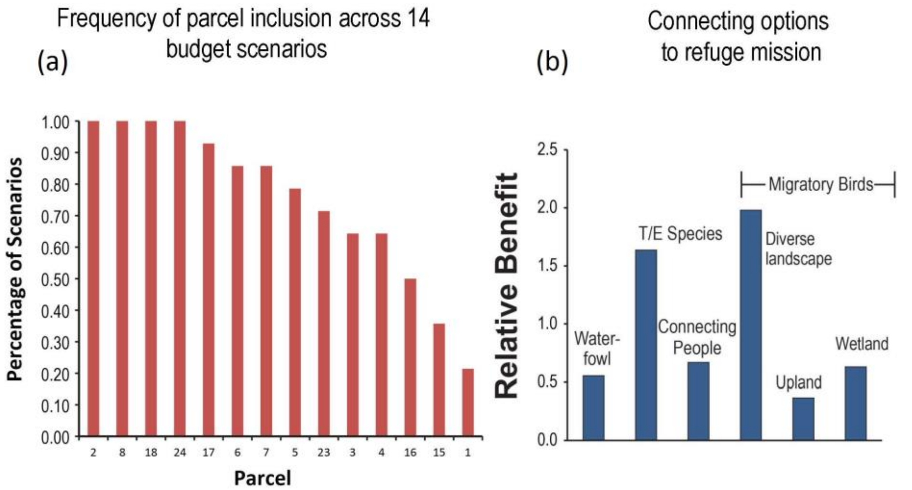

Figure 10. Examples of trade-off analyses: (a) sensitivity of individual parcel selection to budget scenarios; (b) decomposing decision portfolio benefits by individual objectives.

a given outcome.

Additional Considerations

Partnerships and other decision-makers

Although partnerships are an important component of current refuge operation and sustainability, partnerships with and public support from other decision makers and stakeholders is critical for expansion of CRNWR and, therefore, for the longevity of the refuge. Examples of the kinds of stakeholders whose interests and decisions may directly or indirectly influence the outcomes for fundamental resource objectives (NAWMP, T&E species and migratory birds in decline) include, in no particular order: commercial anglers; large private landowners; large public landowners; non-governmental organizations; public agencies that enforce state or federal laws/regulations that affect habitat; friend of the refuge groups; volunteers; state/federal agencies (e.g., Departments of Transportation); local and county governments; small businesses such as lodging and restaurant owners who benefit from ecotourism. Decisions and actions by these stakeholders may influence the availability of habitat in a positive or negative direction. Political support is another crucial component for implementation of any expansion plan, regardless of the availability of land and willingness of potential sellers. Engendering political support will likely be most effective if the objectives of these decision makers are considered when quantifying the value of the refuge or refuge system. This understanding presents an opportunity to reframe the metrics used for appraising the value of the refuge; i.e., scaling the evaluation of benefits to match the decision context of a broader set of stakeholders whose interests are focused on the refuge's production of goods and services for increased human benefit.

Recommendations and Next Steps

This document represents a summary of a week-long prototyping exercise designed to sketch the various components of the decision problems faced by CRNWR and gain insights for a solution approach that will eventually make use of more accurate representations of refuge objectives and the critical complexities that impede management decisions. A great deal of additional work is needed.

Not in order of priority, a subset of recommendations for future efforts includes:

- Develop realistic assessments, at appropriate level of detail, of exposure to global change processes (e.g., SLR; urban expansion; marsh migration and other vegetation/habitat transitions over time) that will affect refuge operation at its current location and possible future expansion area.
- Collaborate with subject matter experts in economic/resource valuation to refine objective performance metrics to best characterize and predict the values and services produced by the refuge over time. Such an evaluation will allow us to anticipate declines in the value of the current refuge as the dynamics of global change stressors reduce habitat and ecosystem functions and to quantify the benefits of a given reserve design strategy for mitigating such losses. A host of economic valuation tools exists to quantify these nonmarket benefits and costs, such as choice experiments, contingent valuation, hedonic property value models, and recreational demand analysis. Benefits transfer techniques provide a reasonable and efficient approach to quantify the value of a great many different ecological services (Bergstrom and Taylor 2006). In addition to employing standard economic valuation methods, the use of both monetary and nonmonetary valuation approaches could be explored to evaluate the implications of using a nonmonetary valuation framework over a traditional monetary approach. Addressing the incorporation and impact of temporal discounting will be an integral part of this evaluation.
- Using appropriate modeling techniques, apply these assessments to predict the impacts of dynamic coastal processes on the specific refuge objectives over a 40-75 year time horizon. Using our best understanding of future conditions (with uncertainty) and metrics that unambiguously relate these state conditions to our appraisal of landscape value, we can estimate the longevity of the current refuge for meeting management objectives and make an informed assessment about if, when and where refuge expansion/migration will result in greater benefits.
- To identify those parcels of land in need of protection in order to sustain refuge objectives and the broader public good, explore existing theory and methods available for calculating optimal solutions to dynamic problems of spatial prioritization (i.e., dynamic reserve design; McDonald-Madden et al. 2008). The traditional, static reserve design problem may not be appropriate in terrestrial

systems, where many parcels may be in private ownership and must be secured on the open market. Thus, it is likely that a reserve design will have to be implemented incrementally, which then exposes the decision maker to resource, environmental, and socio-economic conditionals that can change dramatically over time.

- Explore the use of modern portfolio theory (Ando and Mallory 2012, Hoekstra 2012) to integrate both short- and long-term refuge decision into a common analytical framework. Portfolio theory attempts to confront risk by diversifying assets making the portfolio less sensitive to deviations in expectations by quantifying both the expected return and the deviation from expectations. Both short-term (protect/defend) and long-term (adapt/relocate) actions have immediate costs, but their benefit returns occur at different timescales. Portfolio theory can assist in assessing cumulative benefits in order to optimize the decision portfolio. However, additional model development is needed to confront the reality that asset allocation can (and should) change over time to reflect system dynamics. This complexity represents a new area of research in adaptive portfolio optimization, which could account for both anticipated system state change and state/time-specific portfolio optimization.
- Re-visit trade-off analysis approach to verify appropriateness – e.g., is bias introduced by evaluating predictions of both migratory bird abundance & distribution and the availability of various habitat types? Implement trade-off analyses that account for uncertainty (e.g., environmental uncertainty, structural uncertainty).
- Identify other key partners and stakeholders to refine objectives to represent a broader decision context. Care should be taken when selecting partners to ensure a productive match is made between the decision context and what/whose objectives are being sought. Too broad a set of objectives and the refuge loses autonomy over its own future; too narrow and the relevance of the refuge to society is diminished and future support by influential partners is eroded.
- Further develop the means objectives, performance measures and an analytical process for assessing changes in the probability of long-term refuge sustainability (Objective 5) as additional effort is allocated to foster partnerships and engender public/private support for CRNWR.
- Develop a framework to better relate refuge to regional-scale objectives to facilitate more appropriate matching of decision context to ecological processes
- Begin coordination with other refuges on the Atlantic coast to characterize their decision problems and develop a similar solution framework that will benefit from and contribute to efforts at sister coastal refuges.

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